Pattern and Impact of Altered Regional Myocardial Excursion on Global Ventricular Performance after First-time Acute Anterior Wall Myocardial Infarction by Real-time Three-dimensional Echocardiography

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SUMMARY

Background: The regional wall motion score index obtained by two-dimensional echocardiography in myocardial infarction (MI) has a significant impact on left ventricular (LV) global contractility and is of extraordinary prognostic value, whereas data regarding real-time three-dimensional echocardiography (RT-3DE) are lacking. We sought to clarify the relationship between RT-3DE and LV contractility in patients after MI.

Methods: RT-3DE was performed in 50 patients with anterior wall acute myocardial infarction and 30 normal controls. Global (16 segments) and regional ring-based LV systolic excursions were analyzed offline using the commercially available software Q-Lab version 5.0. The correlations between the LV global and regional systolic excursions and the global LV contractile performance were examined in the MI patients, and further compared with the control group.

Results: The global and regional (basal and middle ring-based) LV systolic excursions were lower in the MI patients (age, 61.8 ± 13.1 years) than in the normal controls (age, 40.0 ± 15.4 years). Global excursion showed inverse linear relationships with LV end-systolic volume ($r = -0.26$, $p < 0.05$) and end-diastolic volume ($r = -0.22$, $p < 0.05$) but no significant relationships with LV ejection fraction ($p = 0.08$) and stroke volume ($p = 0.49$).

Conclusion: Regional wall motion abnormalities quantified by RT-3DE are clinically convenient and feasible in both MI patients and the normal population. This rapid and objective quantification may also help discriminate abnormal from normal regional and global functions after infarction and, therefore, has the potential to be an attractive solution for clinical diagnosis. [International Journal of Gerontology 2008; 2(4): 196–205]

Key Words: anterior wall acute myocardial infarction, global ventricular performance, real-time three-dimensional echocardiography, regional myocardial excursion

Introduction

The conventional regional wall motion score index obtained by two-dimensional (2D) echocardiography in patients with myocardial infarction (MI) and coronary artery disease is of extraordinary prognostic value[1,2]. However, this visual interpretation remains subjective with higher variability, and may rely on the reader's experience to a large extent[3,4]. In addition, the partial information obtained about the cardiac structure and anatomy by traditional 2D echocardiography is limited by the cross-sectional planes without fully exploiting the volumetric information owing to the lack of detailed spatial resolution[5]. Although previous three-dimensional (3D) studies by multiplane acquisition

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have been clinically promising in their spatial resolution, they are time-consuming and prone to artifacts[6]. However, recent advances in 3D transducer design and computing technology have led to more rapid processing of dataflow, by using fast scanning with real-time image acquisition and overcoming the shortcomings of conventional 2D echocardiography. These improvements in both hardware and software design may lead to more accurate assessments of left ventricular (LV) volume[7], mass[8,9], surrounding anatomy and function[10] from a single position without geometric assumptions[11,12]. Good agreement between the emerging real-time 3D echocardiography (RT-3DE) reconstruction technique and magnetic resonance imaging (MRI) has been proven[4,6,7,13], and the technique is convenient, widely feasible and noninvasive for clinical applications.

The semiautomatic border detection strategies in the different software programs used for objective analyses of RT-3DE datasets offer diverse means for potential evaluations of global and regional functions[4,12,13]. Corsi et al.[5] reported good validation and high accuracy between RT-3DE and cardiac MRI for objective global and regional volumetric quantifications in subjects with dilated cardiomyopathy and coronary artery disease. This novel approach provides accurate, fast and semiautomatic quantification of regional LV function by calculating the regional ejection fraction using a similar algorithm to that applied to MRI[13]. In the present study, we hypothesized that using RT-3DE for objective quantifications of LV regional and global functions may provide rapid and accurate measurements and aid in identifying wall motion abnormalities in patients with anterior wall MI. We further sought to investigate the impacts of the regional functional abnormalities detected by RT-3DE on LV global performance in our patient population.

Materials and Methods

Study population

This study involved 50 patients with anterior wall MI and 30 normal volunteers. The 50 patients with anterior wall MI were selected from the local emergency department for primary angioplasty based on good-quality images. The criteria for anterior wall MI were defined as: (1) chest pain of more than 30 minutes; (2) persistent ST segment elevation of more than 1 mm from the baseline in precordial leads; and (3) evidence of culprit left anterior descending coronary artery lesion by angiogram or documented elevated cardiac enzymes. All echocardiography images, including M-mode and 2D images, were obtained within 12 hours of acute myocardial infarction (AMI) after primary angioplasty. A cardiac marker (troponin I) was repeatedly measured three times after AMI using the Immulite cTnI assay (DPC, Gwynedd, Wales, UK) based on the principle of chemiluminescence, and the highest value was used for analyses. Patients with previous cardiac surgery, morphologically abnormal cardiac valves, old MI, or previous heart surgery according to medical records were excluded from the study. The study was approved by the local Ethics Committee and all patients provided oral informed consent to participate in the study.

Echocardiographic assessments

All echocardiograms including M-mode, Doppler and 2D images were digitized from the DICOM format acquired by iE33 (Philips, Andover, MA, USA), and analyzed using an offline workstation. The left atrial (LA) area was measured by manual tracing from a four-chamber view at the end-systolic phase at one frame before mitral valve opening. The LV mass was calculated from the LV linear dimension using the formula recommended by the American Society of Echocardiography. The mitral regurgitation grade was expressed as the proportion of the LA area by tracing the largest jet area in the LA from four-chamber views from the start of the QRS complex to the end-systole phase. The LV mass was obtained by the cube formula using the correction described by Devereux et al.[14]: LV mass (g) $= 0.8 \times \{1.04 \times [(\text{interventricular septum} + \text{LV internal diameter} + \text{posterior wall thickness})^3 - \text{LV internal diameter}^3]\} + 0.6$. The LV functional systolic indices, including the LV end-diastolic volume (LVEDV) and LV end-systolic volume (LVESV) in milliliters and derived LV ejection fraction (LVEF), were all quantified offline using Q-Lab version 5.0 (3DQ version 6.0).

Transthoracic RT-3DE

A real-time pyramidal 3D full-volume dataset was acquired with a second-generation matrix array iE33 (Philips, Andover, MA, USA) X3-1 transducer. The full-volume dataset was composed of four smaller pyramidal real-time subvolumes (93 × 20 degrees each) from four continuous cardiac cycles with QRS complex gating and breath-hold at the end-expiratory phase of each participant from LV apical views. A wide-angled mode was chosen for image acquisition, and care was taken to include the entire LV cavity within the scan volume. For better structural and geometric display, the depth was minimized to contain the mitral and aortic valves for further landmark definition and spatial orientation. At least three full-volume acquisitions were performed for each participant and the best endocardial border was analyzed. All data were stored on CD-ROM discs and then transferred to a workstation for further offline analyses by the Q-Lab software. Quantitative analyses included predefined offline landmarks (basal septal, basal lateral, basal anterior and basal inferior points) under assumed spatial and structural orientations in each full-volume dataset using dedicated custom software packages with dynamic frame-by-frame endocardial borders tracked semiautomatically. Estimation of time-volume curves corresponding to the global LV and regional volumes was based on the 17-segment model (segment 17 was excluded in our study owing to possible poor image quality in some cases) suggested by the American Heart Association Writing Group on Myocardial Segmentation and Registration for Cardiac Imaging[15]. The baseline LVEDV, LVESV and LVEF were provided by the same software, with the papillary muscles included and the LV outflow tract precluded in these LV volume measurements.

Definition of LV global and regional systolic excursion indexes

Time–volume curves from 16 global average segments using all individual segments were obtained and analyzed automatically using ring-based (basal, middle and apical rings) and 16-segment models after frame-by-frame tracking of the endocardial border (Figure 1). The time period from the QRS wave to the minimal volume toward the central axis by systolic excursion was generated automatically by the software. To enable accurate and precise volume measurements, the original dataset from Q-Lab was transferred into SigmaPlot version 10.0 (RockWare Inc., Golden, CO, USA) for multiple spline curve line analyses with electrocardiogram gating. The fractional volume change of the difference in the 16 individual segments from this dynamic excursion between the end-diastolic and end-systolic phases was defined as the systolic excursion index (SEI) for regional functional evaluation.

The ring-based SEI models used in our study were derived from the following formulas:

- basal ring SEI = (SEI from all six basal segments)/6
- middle ring SEI = (SEI from all six middle segments)/6
- apical ring SEI = (SEI from all four apical segments)/4

The average SEI values from the ring-based and 16-individual-segment models were defined as the global SEI and used for global functional evaluation.

Statistical analysis

All data are presented as mean ± standard deviation. Linear correlations were used for comparisons among LV volume, LVEF and SEI obtained by RT-3DE. Continuous variables were compared between the AMI patients and normal volunteers by an unpaired Student's *t* test, while categorical variables were compared by the χ^2 test. The global SEI and regional SEI (including ring-based and 16-individual-segment models) were compared between the AMI patients and normal controls by a two-sample Wilcoxon rank sum (Mann-Whitney) test. All statistical analyses were performed with STATA software version 8.0 (Stata Corp., College Station, TX, USA). Values of $p < 0.05$ were considered statistically significant.

Reproducibility

A total of 12 cases were randomly chosen for reproducibility analysis by two different clinicians blinded to each other. The LVEDV, LVESV and global SEI were all chosen for repeated analysis. The interobserver and intraobserver variabilities by Bland-Altman analysis for LVEDV, LVESV and global SEI were 4.8%, 4.2% and 5.3%, respectively.

Results

Baseline data

The baseline demographic and echocardiographic data of the 50 patients with AMI (19 are females; mean age, 61.8 ± 13.1 years) are shown in the Table. Compared with the normal controls, the AMI patients were older and included more females. The AMI patients had relatively lower LV systolic function (LVEF, 53.4% ± 10.0% vs. 63.13% ± 7.06%; $p < 0.001$) and mildly elevated LV mass (134.48 ± 33.37 vs. 100.36 ± 21.13 g; $p < 0.001$) compared with the normal controls. In addition, the AMI patients had elevated LA area, LVEDV and LVESV compared with the normal controls ($p < 0.001$). Mildly reduced renal function was observed in the AMI patients. The β-blocker usage among the AMI patients was high, with a lower rate of calcium channel blocker usage.

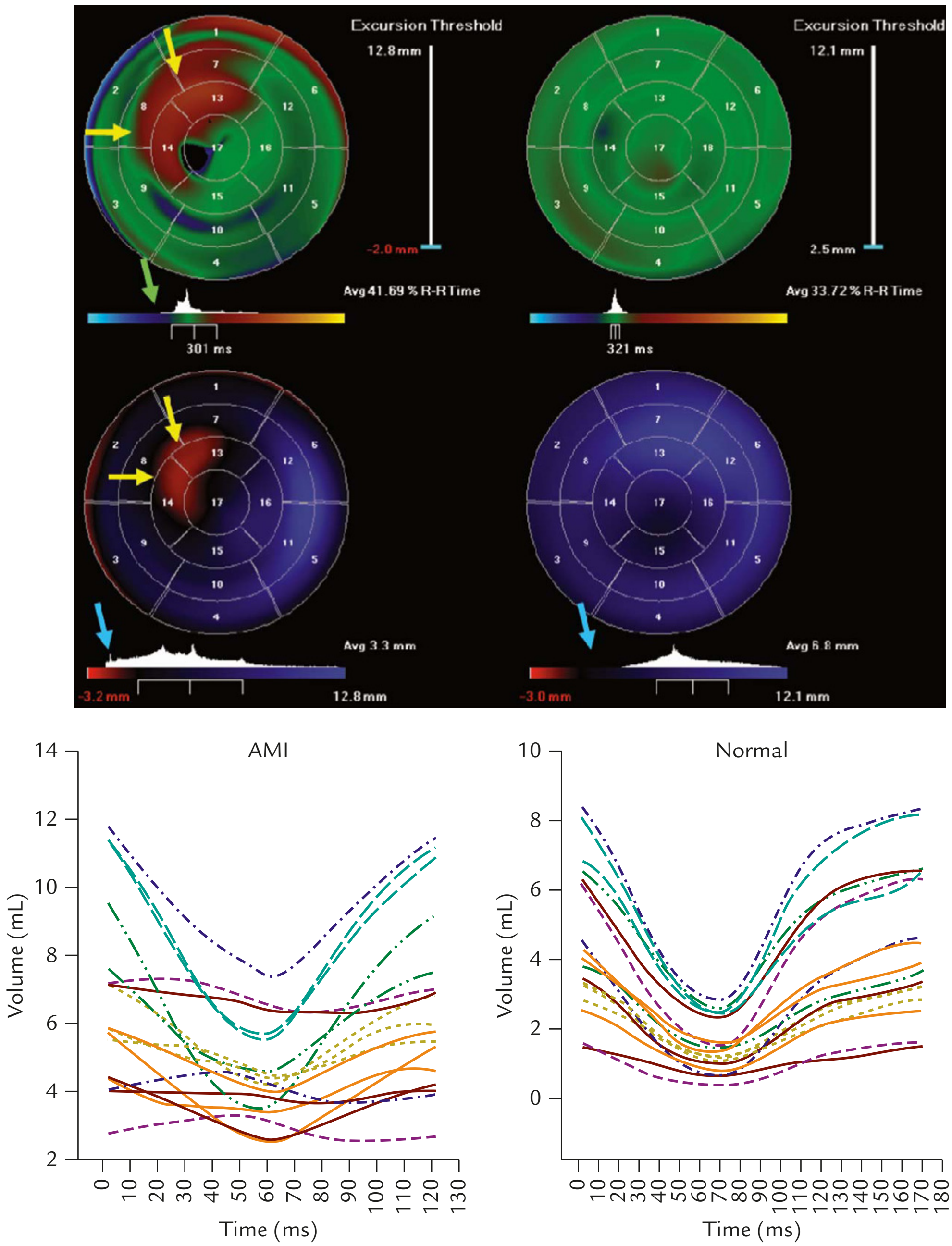

Figure 1. Bull's-eye maps illustrating the acute myocardial infarction (AMI) patients and normal controls. Post-processing real-time three-dimensional echocardiography polar map analyses reveal both phases and excursions in the bull's-eye maps. Time–volume curves of all 16 segments are illustrated under the bull's-eye maps. The left panel shows an AMI patient with akinesia–dyskinesia by two-dimensional echocardiography, and the right panel shows a normal control without significant wall motion abnormalities. In the AMI patient, the yellow arrows indicate a wall motion abnormality with delayed and widely distributed motion (left upper panel; yellow arrows on the red regions in the bull's-eye map), indicating possibly heterogeneous contraction timing. In addition, there is a more randomly distributed and even paradoxical excursion (left lower panel; yellow arrows on the red regions in the bull's-eye map) in the AMI patient arising from regional wall motion abnormalities.

Global LV SEI versus conventional LV systolic functional index

The global SEI was associated with LV global systolic function and volume (Figure 2). Higher global SEI values were associated with lower LVESV and LVEDV values. There was also a trend for an association between higher SEI values and higher global LVEF values. There was no obvious relationship between the global SEI and stroke volume values. The results of a comparison between the global SEI values of the AMI patients and normal

Table. Baseline demographic and echocardiographic data in the current study*	AMI patients ($n=50$)	Normal controls ($n=30$)	p
Age (yr)	61.84±13.11	40.03±15.36	<0.001
Female gender	14 (28)	17 (56.7)	0.011
Systolic blood pressure (mmHg)	128.42±21.22	121.14±11.24	0.12
Heart rate (/min)	71.34±11.14	70.93±13.25	0.88
Diabetes mellitus	17 (34)	–	
Hypertension	20 (40)	–	
Blood urea nitrogen (mg/dL)	19.64±13.04	–	
Creatinine (mg/dL)	1.42±1.08	–	
Troponin I	23.73±38.07		
Medication			
Angiotensin-converting enzyme inhibitor	34 (68)	–	
Angiotensin II receptor blocker	21 (42)	–	
Calcium channel blocker	19 (38)	–	
β-blocker	40 (80)	–	
Baseline echocardiographic data			
LVEF (%)	53.41±10.03	63.13±7.06	<0.001
LVESV (mL)	42.76±15.60	26.39±9.46	<0.001
LVEDV (mL)	90.85±22.22	70.37±15.88	<0.001
Stroke volume (mL)	48.10±13.75	43.99±8.95	0.15
Left atrial area (cm^2)	16.79±3.25	12.64±2.38	<0.001
Left ventricular mass (g)	134.48±33.37	100.36±21.13	<0.001

Data are presented as mean±standard deviation or n (%). AMI = acute myocardial infarction; SD = standard deviation; LVEF = left ventricular ejection fraction; LVESV = left ventricular end-systolic volume; LVEDV = left ventricular end-diastolic volume.

controls are shown in Figure 3A. The global SEI was lower in the AMI patients than in the normal controls ($z=2.16$, $p=0.03$).

Differences in the regional functional index between the AMI patients and normal controls

A total of 1,280 regional myocardial segments were analyzed in this study. The differences in the ring-based SEI values between the AMI patients and normal controls are shown in Figure 3B. There was a significant difference in the basal ring SEI values between the two groups ($p=0.02$), with a borderline significant difference in the middle ring SEI values ($p=0.05$). The difference in the apical ring SEI values between the two groups was not significant ($p=0.25$).

The results of comparisons of individual SEI values from the ring-based and 16-segment models between the AMI patients and normal controls are shown in Figure 4. Lower SEI values were generally observed in the AMI patients. The corresponding SEI values of each segment are also shown in Figure 4 as a bull's-eye map. Compared with the value for the normal controls, the SEI values of the basal anteroseptal, basal inferoseptal, mid-anterior, mid-anteroseptal, and apical-lateral segments were significantly lower in the AMI patients. In addition, there was a trend without statistical significance toward lower SEI values in the basal anterior, basal inferior, basal anterolateral, mid-inferoseptal, and mid-inferolateral segments in the AMI patients compared with the normal controls.

Discussion

In the current study, we tried to depict regional and global myocardial functional abnormalities in AMI patients by utilizing the quantitative RT-3DE method. We also tried to correlate such global and regional functional abnormalities with traditional LV functional indexes, including LVEF and LV volumes. The AMI patients in our study comprised cases with relatively preserved global LVEF (average, 53.41%±10.03%) owing to smaller infarct

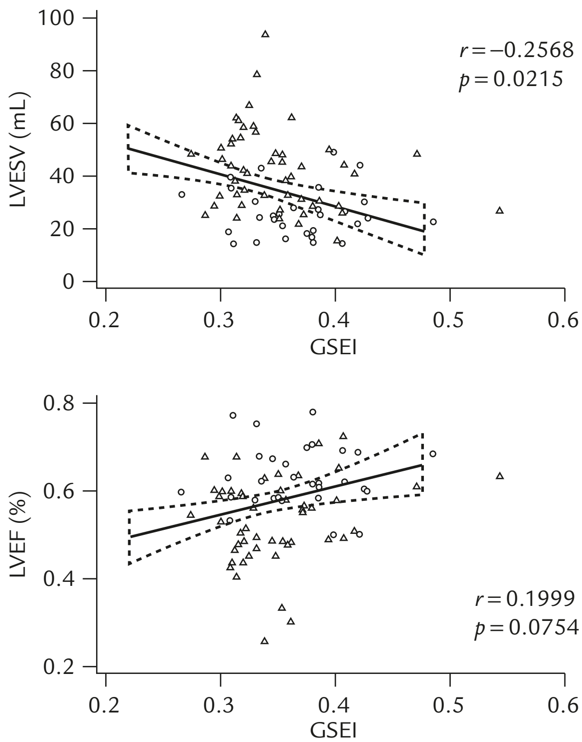

Figure 2. Relationships between the global systolic excursion index (GSEI) and conventional left ventricular (LV) functional indexes. A reduced GSEI is associated with higher LV end-systolic volume (LVESV) and LV end-diastolic volume (LVEDV), and a trend toward a reduced LV ejection fraction (LVEF). There is no significant relationship between the GSEI and stroke volume (SV). The triangular points represent acute myocardial infarction (AMI) patients and the circular points represent normal controls.

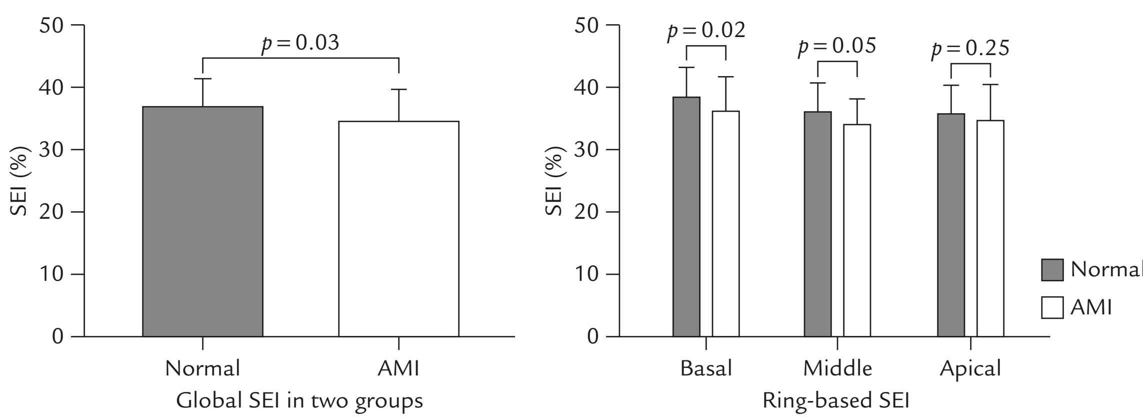

Figure 3. Comparisons of global and ring-based systolic excursion indexes (SEIs) between the acute myocardial infarction (AMI) patients and normal controls. A significant difference in the global SEI is observed between the AMI patients and normal controls. A higher global SEI is observed in the normal controls.

sizes, which may make the roles and discriminative values of minor functional abnormalities detected by RT-3DE important. Anterior wall AMI has been shown to be associated with worse outcomes after MI[16,17], and early detection and subsequent treatment strategies are therefore crucial. Regional myocardial functional evaluation by traditional visual assessment on 2D echocardiographic images has been achieved with ease by effective integration of spatial and temporal information[4]. Although proven to be of clinical prognostic value[2], this assessment is limited by its subjective interpretation. More objective quantification alternatives based on frame-by-frame manual or semiautomatic tracing of endocardial borders, such as acoustic quantification[18], color kinesis[19], myocardial Doppler imaging[20] and myocardial deformation imaging[21], are not

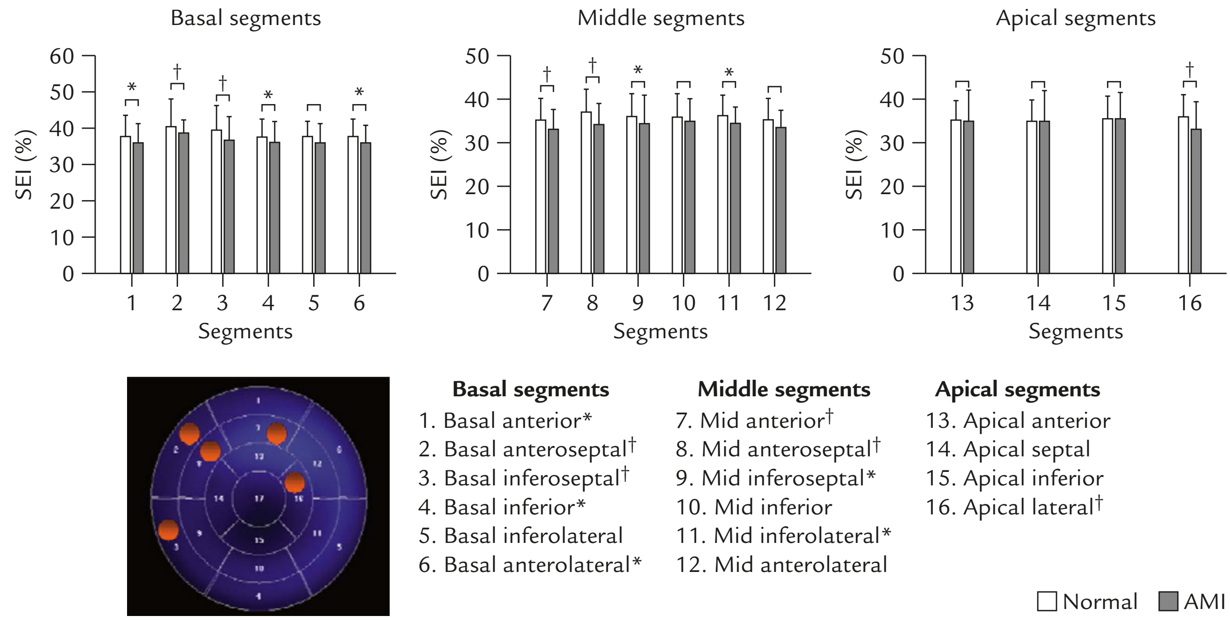

Figure 4. Comparisons of the systolic excursion indexes (SEIs) from corresponding regional 16-segment models between the acute myocardial infarction (AMI) patients and normal controls. Comparisons of the SEI values according to the 16-segment model between the AMI patients and normal controls reveal that the SEI values are generally lower in the AMI patients. Segments with significantly different SEI values between the AMI patients and normal controls are marked with orange circles in the bull's-eye map. *$p < 0.10$ between the AMI patients and normal controls; †$p < 0.05$ between the AMI patients and normal controls.

widely used owing to their higher technical demands and time-consuming processes. Furthermore, the lack of a fully encompassed LV structure from routine 2D cutting planes may not provide sufficient information or may miss delicate changes in patients with localized small infarcts and limited regional abnormalities.

In recent years, with advances in echocardiography and software design, instantaneous acquisition and analysis of 3D full-volume echocardiography datasets over the whole cardiac cycle have become possible[22,23]. In addition to its ability to fully exploit cardiac structures by additional dimensionality with increased avoidance of foreshortening, RT-3DE has potential for dynamic global and regional volumetric and functional evaluations by reconstruction[11]. Previous studies have demonstrated good correlations between traditional 2D echocardiography and RT-3DE for regional wall motion abnormalities, with shorter scanning times and improved interobserver agreements associated with RT-3DE[3,24]. In addition, satisfactory results for RT-3DE compared with other imaging modalities, such as MRI[5,8,9] or single photon emission computed tomography[25], in regional myocardial function and myocardial dyssynchrony measurements[26] have been well documented. In our study, a reduced global SEI was associated with lower global LV performance and worse function related to higher LVESV and LVEDV, with a trend toward a lower LVEF. The stroke volume was not strongly associated with the global SEI, which may be partially explained by the adaptive LV enlargement (infarct expansion) process associated with both enlarged LVEDV and LVESV required to maintain adequate cardiac output in patients with MI[27,28]. In addition, this observation is supported by previous findings that expansion of infarct zones leading to larger global volume can happen early after MI[27]. More importantly, the dynamic wall excursion or radial movement described by RT-3DE is actually different from that detected by tissue Doppler imaging, which is essentially based on longitudinal myocardial shortening[16]. Although longitudinal behavior seems to be more sensitive and susceptible to myocardial ischemia[29], the effective excursion behavior observed by RT-3DE may contribute more to the global LVEF. Interestingly, we observed that the ring-based SEI differed significantly in the basal segments, whereas the middle ring-based SEI exhibited only a borderline significant difference. There was no significant difference in the apical ring-based SEI between the AMI patients and normal controls. These observations may arise from the inherent endocardial border tracking characteristics rather than the myocardial motion *per se*, based on volumetric measurements by the RT-3DE algorithm. In addition, the endocardial boundary is less well defined by RT-3DE in the apical region, which may lead to inadequate information for detailed discrimination[5].

In our study, all the SEI models seemed to be lower in the AMI patients than in the normal controls, although only five segments achieved significant differences compared with the normal controls. This generalized reduction in SEI from all segments may arise from lower global systolic function and index values in the AMI patients with altered geometry and higher volume. Interestingly, five of the total 16 cardiac segments in the AMI patients did show significantly reduced SEI values compared with the normal controls. These segments are compatible with previous experience of regional abnormalities theoretically observed after anterior wall infarction[30], which may make clinical assessment, automatic quantification, and detection of the infarct territory possible.

Limitations

The high dependency of good endocardial border detection with interpolated tracking by the RT-3DE algorithm also makes poor cardiac windows from rib shadows or echocardiographic dropout uninterpretable. Compared with traditional 2D loop images, the lower frame rate of RT-3DE is a major limitation. In addition, the lower relative frame rate system in RT-3DE may limit the temporal resolution in patients with higher heart rates caused by physical stress as mentioned before. Furthermore, the lower temporal resolution may not correctly depict the trivial degrees of SEI in each segment. In subjects with higher heart rates due to physiologic stress, shortened cycle length may lead to even lower frame counts in one heart cycle, thereby leading to difficulties in precise evaluation of minor changes and abnormalities on the regional time–volume curves. In a previous regional wall motion scoring system by visual estimation on 2D images, the extent to which this limited temporal resolution impacts on the regional functional evaluation by RT-3DE remains unknown. Recent studies using MRI or RT-3DE did reveal a high degree of agreement between these two methodologies. However, other imaging modalities, such as tissue Doppler imaging, tissue velocity imaging using a high frame rate system and 2D speckle-tracking techniques, had higher frame rates than RT-3DE.

Another major limitation of RT-3DE comes from the sequential image acquisition by the X3-1 transducer for several continuous heart beats. This prolonged period of image acquisition by RT-3DE may lead to vulnerable cardiac motion or translation and misalignment of the cut planes, and thus breath holding is suggested. Patients with tachypnea or tachycardia under physiologic stress may not be able to tolerate the whole breath holding procedure. Owing to the necessity of electrocardiogram wave gating in image acquisition, patients with major arrhythmias and irregular cycle lengths may fail to provide good datasets for further analysis.

Conclusion

LV functional evaluation by RT-3DE volumetric excursion analysis has proven to be clinically feasible and convenient in our study, even in patients with MI. This rapid and objective quantification may also help discriminate abnormal from normal regional and global functions after infarction, and therefore has the potential to be an attractive solution for clinical diagnosis.

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